FINAL REPORT

THE EFFECT OF ULTRAVIOLET (UV-B) RADIATION ON ENGLEMANN SPRUCE AND LODGEPOLE PINE SEEDLINGS

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EPA-IAG-D6-0168

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Prepared for
Environmental Protection Agency
BACER Program
Washington, D.C. 20460

ABSTRACT

Engelmann spruce and lodgepole pine are conifers found at high elevations (2,700 to 3,300 m) in the central Rocky Mountains. UV-B enhancement and exclusion studies were performed at about 2,980 m on transplanted seedlings. Enhancement studies were performed using standardized light banks consisting of two FS-40 sunlamps in each of two fixtures 60 cm apart and 110 cm above the seedlings. Cellulose acetate and Mylar filters were used along with an untreated control to provide appropriate UV-B treatments, with seedlings arrayed to vary the amount of supplementary radiation. Treatments extended for 67 days, with supplementary radiation for a cumulative period of 400 hours. Exclusion studies were performed to compare the effects of UV-B in natural sunlight. Seedlings were placed under filters of cellulose acetate or Mylar, under lath shade, or in the open to provide different UV-B treatments.

Careful visual observations of the seedlings by several scientists indicated no symptoms (color, necrosis, growth form, etc.) for any of the treatments, either during the study period or in the subsequent 2-1/2 months before the seedlings were covered by snow. Analyses of growth (length of terminal leader, number and length of lateral branches) indicated no major effect of treatments, either in the enhancement or in the exclusion study.

Importantly, however, in the natural environment transplanted seedlings of Engelmann spruce do not show symptoms of solar radiation damage until the summer following exposure. Consequently, seedlings are being kept for continued observation to determine whether differences among treatments may appear during the second growing season, perhaps as a result of effects on food reserves and ability to withstand the harsh winter environment of high elevation areas.

This research was done by the U.S. Forest Service Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, under a cooperative agreement with the Agricultural Research Service, Beltsville, MD. and under an agreement with ARS and the Environmental Protection Agency. This report covers the period of Oct. 1, 1976 to Sept. 30, 1977. Except for continuing experimental observations of plants, this work was completed on Dec. 15, 1977.

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INTRODUCTION

The possibility that the intensity of ultraviolet light (UV-B, 280-320 nm) received at the earth's surface will increase is of considerable interest in the high-elevation forest zone of the central Rocky Mountains. Ronco (1970 a and b) concluded that mortality of open-grown Engelmann spruce seedlings was related to intense solar radiation, whereas seedlings of lodgepole pine were not adversely affected by full sunlight. The possibility that solar radiation damage of spruce is caused in part by high levels of UV-B stimulated interest in evaluating the effects of increased levels of UV-B on growth and development of these species.

The research reported here was designed to determine the physiological effects of enhanced UV-B radiation on Engelmann spruce and lodgepole pine and to establish UV-B tolerance levels for these species in high-elevation forest ecosystems.

CONCLUSIONS

Observations were made of the effects of UV-B on vegetative growth, foliage color, and morphological development of new foliage of Engelmann spruce and lodgepole pine seedlings during and after a treatment period extending 67 days (400 total hours of supplemental UV-B radiation).

No significant effects of UV-B enhancement or exclusion were observed during the treatment period or in the subsequent 2-1/2 months before the seedlings were covered by snow. It must be emphasized, however, that in the natural environment transplanted seedlings of Engelmann spruce do not show symptoms of solar radiation damage until after the first winter.

Consequently, it is premature to reach conclusions about the impact on high elevation conifers of UV-B enhancement or exclusion after a single growing season.

RECOMMENDATIONS

No effects of UV-B enhancement or exclusion were observed during a single growing season.

From an experimental standpoint, it is recommended that observations on the treated seedlings continue into the second growing season and that future studies on tree species be long enough to accommodate the perennial, long-term nature of growth and development.

In the context of environmental impact of UV-B, no assessment or recommendation can be made at this time regarding tolerance levels for Engelmann spruce and lodgepole pine.

TEXT

GENERAL OBJECTIVES

Because of thinner atmosphere, solar radiation is attenuated less at high elevations than at low elevations. In most portions of the solar spectrum, including UV-B, intensities are higher at high elevations than near sea level. Thus the study of growth and development of high elevation conifers was designed to include exclusion of natural UV-B as well as enhancement of UV-B, as might occur through ozone depletion in the stratosphere.

The field research was divided into two parts. The exclusion study was conducted to determine if the presence or absence of natural UV-B or a general reduction across the entire solar spectrum had an effect on physiology and vegetative growth of conifer seedlings. Simultaneously, an enhancement study was conducted to determine seedling response to various levels of enhanced UV-B which might result from ozone depletion.

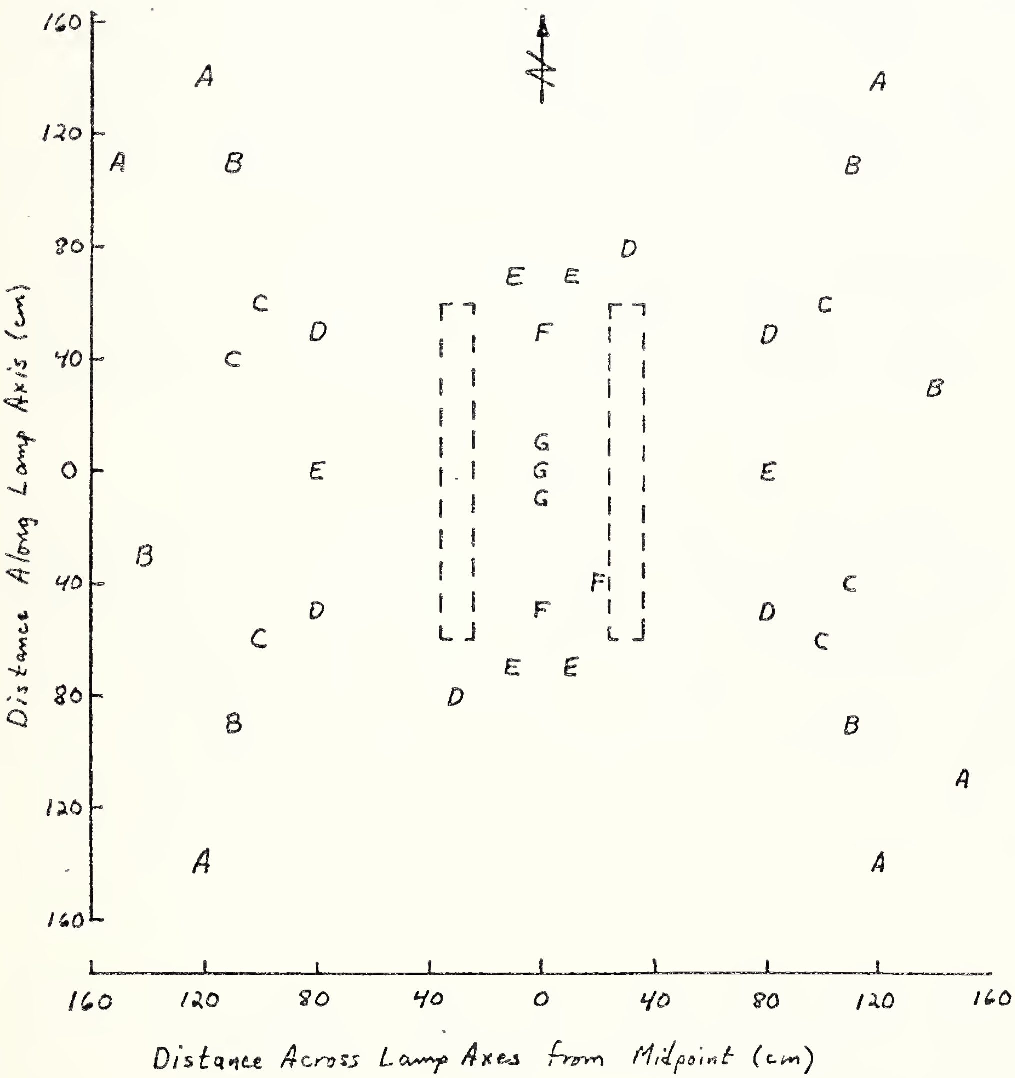
EXPERIMENTAL PROCEDURES

Experiments were conducted near the Elk Camp Restaurant in the Snowmass Ski Area, Snowmass Village, Co. at an elevation of 2,980 m. Experiments were performed using 3-year old Engelmann spruce (*Picea engelmannii* Parry) and 2-year old lodgepole pine (*Pinus contorta* Dougl.) seedlings. The seedlings were grown at the U.S. Forest Service Mt. Sopris Nursery located at Carbondale, CO, about 20 km northwest from the study site and at an elevation of about 2,800 m. Seedlings were potted June 13-15 and exposed to selected treatments.

In the exclusion study, groups of 25 seedlings of each species were exposed to one of four treatments: (1) natural sunlight control; (2) lath shade providing 50 percent interception of noon-day sun; (3) natural UV-B, using a 5 mil cellulose acetate filter; and (4) excluded UV-B, using a 5 mil Mylar filter. Treatments were replicated, and 200 seedlings of each species were used in the study.

The enhancement study utilized natural sunlight plus supplemental radiation from FS-40 lamps. Seedlings were exposed to three treatments: (1) natural sunlight control; (2) plus UV-B, consisting of natural sunlight augmented by FS-40 lamps filtered with 5 mil cellulose acetate; and (3) natural UV-B, consisting of natural sunlight and FS-40 lamps filtered with 5 mil Mylar. Both cellulose acetate and Mylar remove wavelengths below UV-B; cellulose acetate passes UV-B and Mylar removes UV-B. Lamp pairs were located 60 cm apart and 110 cm above the seedlings. Lamps were operated for 6 hr. per day for 67 days of treatment. Seedlings were distributed beneath the lamps to provide seven levels (A through G of UV-B intensity (Fig. 1)). The positions

Figure 1



N
A
A
B
B
C
C
D
D
E
E
F
G
G
G
160
120
80
40
0
40
80
120
160
Distance Along Lamp Axis (cm)
Distance Across Lamp Axes from Midpoint (cm)

were selected to provide supplemental UV-B radiation in the following approximate relationship: A:B:C:D:E:F:G = 0.2:0.4:0.6:0.8:1.0:1.3:1.6. Nighttime measurements with an IRL Spec D spectroradiometer at each seedling indicated these relative values to be substantially correct for the seven radiation levels (Table 1). Thirty-six seedlings of each species were used in each of the three treatments, and all treatments were replicated. Six seedlings were subjected to each of the five lower supplemental UV-B levels (A through E) and three to each of the two highest levels (F and G). A total of 216 seedlings of each species were used in the enhancement study.

Throughout the treatment period, observations were made of the breaking of dormancy of terminal and lateral buds. Particular attention was paid to visual observation of color, deformity, or dwarfing of new foliage. On Aug. 22-24, 1977, after 67 days of treatment, measurements were made of mortality, length of terminal leader (if present), and number and lengths of all lateral branches. No records were made of color or of needle length, since variation within treatments obviously greatly exceeded variation among treatments.

On Aug. 30, 1977, seedlings were moved to the Fraser Experimental Forest, CO. (elevation 2,740 m). Visual observations were continued until mid-November when snow covered the seedlings. Additional observations of mortality and color and condition of 1977 and 1978 growing season foliage will be made during 1978.

RESULTS

During the 67-day treatment period, no treatment differences of any kind were observed in rate of dormancy break or in appearance of foliage from the new flush or from the previous growing season. Failure of the terminal bud of Engelmann spruce to break dormancy ranged from 30 to 52 percent in the exclusion study (Table 2) and from 25 to 83 percent in the enhancement study (Table 3). In lodgepole pine, terminal bud failure was 0 to 8 percent in the exclusion study and 0 to 33 percent in the enhancement study. No significant effects were found among treatments or supplemental radiation levels in either study. The high bud failure in spruce is not important, since a lateral bud on the terminal leader quickly assumes dominance. Seedling mortality ranged up to 8 percent for spruce and to 17 percent for pine in the two studies (Tables 2 and 4), but again, no treatment or radiation level effects were significant.

Vegetative growth data for the exclusion study are summarized in Table 5. No significant treatment effects were observed in terminal leader length (measured on plants whose terminal bud broke dormancy), number of branches, and total and mean branch lengths. Vegetative growth data for the enhancement study are given in Figures 2 and 3 (means with standard deviations and statistical evaluations appear in Tables 6 and 7 in the Appendix). Significant treatment effects were observed on total branch length in Engelmann spruce (Fig. 2C) and on number of branches in lodgepole pine (Fig. 3B). Supplemental radiation effects were significant only for mean branch length of Engelmann spruce (Fig. 2D); however this effect was also observed in the untreated control plants and is probably due to random experimental error. Treatment and radiation level effects in the enhancement

TABLE 1. UV-B RADIATION LEVELS AT DIFFERENT POSITIONS BENEATH LAMPS, MEASURED WITH IRL SPEC D SPECTRORADIOMETER. UNWEIGHTED POWER CONVERTED TO WEIGHTED POWER EQUIVALENTS WITH THE AΣ9 WEIGHTING FUNCTION. VALUES MEASURED AT NIGHT WITH NO NATURAL UV, AT SEEDLING HEIGHT BENEATH LAMPS WITH 5 MIL CELLULOSE ACETATE FILTERS.

Location beneath lamps	Unweighted power ($mW.m^{-2}$)	Weighted power* ($mW.m^{-2}$)
A	47	0.44
B	94	0.88
C	170	1.59
D	204	1.89
E	273	2.52
F	385	3.57
G	478	4.34

TABLE 2. EFFECT OF NATURAL SUNLIGHT, SHADE, AND UV-B ON TERMINAL BUD FAILURE AND SEEDLING MORTALITY IN ENGELMANN SPRUCE AND LODGEPOLE PINE (EXCLUSION STUDY)

Treatment	Terminal bud failure (%)*		Mortality (%)	
	Spruce	Pine	Spruce	Pine
Natural sunlight (control)	32	10	0	8
Lath shade	52	10	0	8
Natural UV-B (cell. acetate)	40	4	2	4
Excluded UV-B (Mylar)	30	0	2	0
Significance	N.S.**	N.S.	N.S.	N.S.

* Includes trees which died.

** N.S. = not significant at P = 0.05.

TABLE 3. EFFECT OF UV-B RADIATION LEVELS ON TERMINAL BUD FAILURE IN ENGELMANN SPRUCE AND LODGEPOLE PINE (ENHANCEMENT STUDY)

	Terminal bud failure (%)*						
	Supplemental radiation level						
Treatment	A	B	C	D	E	F	G
Engelmann spruce							
Natural sunlight (control)	42**	33	67	33	50	67	67
Plus UV-B (lamp with cell. acetate)	42	58	58	33	58	33	50
Natural UV-B (lamp with Mylar)	25	50	42	67	83	50	50

** Radiation level and treatment effects not significant (P = 0.05)

	A	B	C	D	E	F	G
Lodgepole pine							
Natural sunlight (control)	8**	0	0	8	8	17	17
Plus UV-B (lamp with cell. acetate)	0	0	8	0	17	17	33
Natural UV-B (lamp with Mylar)	0	8	8	8	8	0	0

* Includes trees which died

** Radiation level and treatment effects not significant (P = 0.05)

TABLE 4. EFFECT OF UV-B RADIATION LEVELS ON MORTALITY IN ENGELMANN SPRUCE AND LODGEPOLE PINE (ENHANCEMENT STUDY)

	Mortality (%)						
	Supplemental Radiation Level						
Treatment	A	B	C	D	E	F	G
Engelmann spruce							
Natural sunlight (control)	0*	0	0	8	8	0	0
Plus UV-B (lamp with cell. acetate)	0	8	0	0	8	0	0
Natural UV-B (lamp with Mylar)	0	8	0	0	0	0	0

* Radiation level and treatment effects not significant (P = 0.05)

	Mortality (%)						
	Supplemental Radiation Level						
Treatment	A	B	C	D	E	F	G
Lodgepole pine							
Natural sunlight (control)	0*	0	0	8	0	0	17
Plus UV-B (lamp with cell. acetate)	0	0	0	0	17	17	17
Natural UV-B (lamp with Mylar)	0	8	8	8	8	0	0

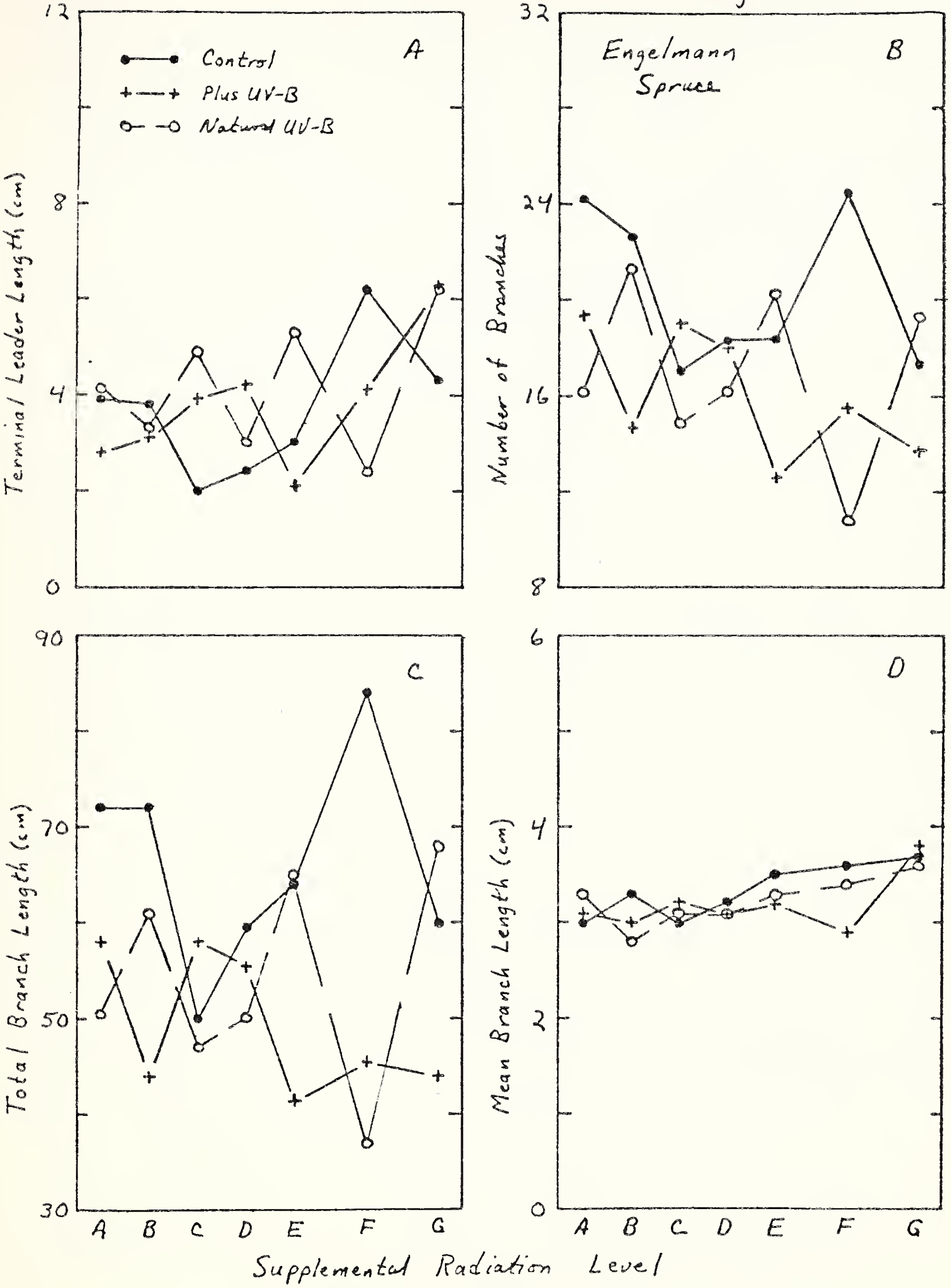
* Radiation level and treatment effects not significant (P = 0.05)

TABLE 5. EFFECT OF NATURAL SUNLIGHT, SHADE, AND UV-B ON VEGETATIVE GROWTH OF ENGELMANN SPRUCE AND LODGEPOLE PINE (EXCLUSION STUDY). VALUES ARE MEANS AND STANDARD DEVIATIONS

Treatment	Terminal leader length (cm)	Number of branches	Total branch length (cm)	Mean branch length (cm)
<u>Engelmann spruce</u>				
Natural sunlight (control)	4.7 ± 3.0	19.8 ± 10.9	67.4 ± 36.0	3.5 ± 0.8
Lath shade	5.1 ± 2.0	17.4 ± 11.2	60.5 ± 39.1	3.5 ± 0.7
Natural UV-B (cell. acetate)	4.6 ± 2.4	17.3 ± 10.3	59.2 ± 33.4	3.3 ± 0.7
Excluded UV-B (Mylar)	5.0 ± 2.4	17.1 ± 8.0	57.4 ± 25.7	3.5 ± 0.5
Significance	N.S.*	N.S.	N.S.	N.S.
<u>Lodgepole pine</u>				
Natural sunlight (control)	6.4 ± 2.1	7.0 ± 3.3	15.1 ± 8.0	2.2 ± 0.8
Lath shade	6.2 ± 2.4	7.8 ± 3.8	15.2 ± 8.0	2.1 ± 1.0
Natural UV-B (cell. acetate)	6.4 ± 2.5	9.3 ± 4.1	18.5 ± 8.0	2.1 ± 0.8
Excluded UV-B (Mylar)	6.0 ± 2.4	9.5 ± 4.9	16.2 ± 8.2	1.8 ± 0.7
Significance	N.S.*	N.S.	N.S.	N.S.

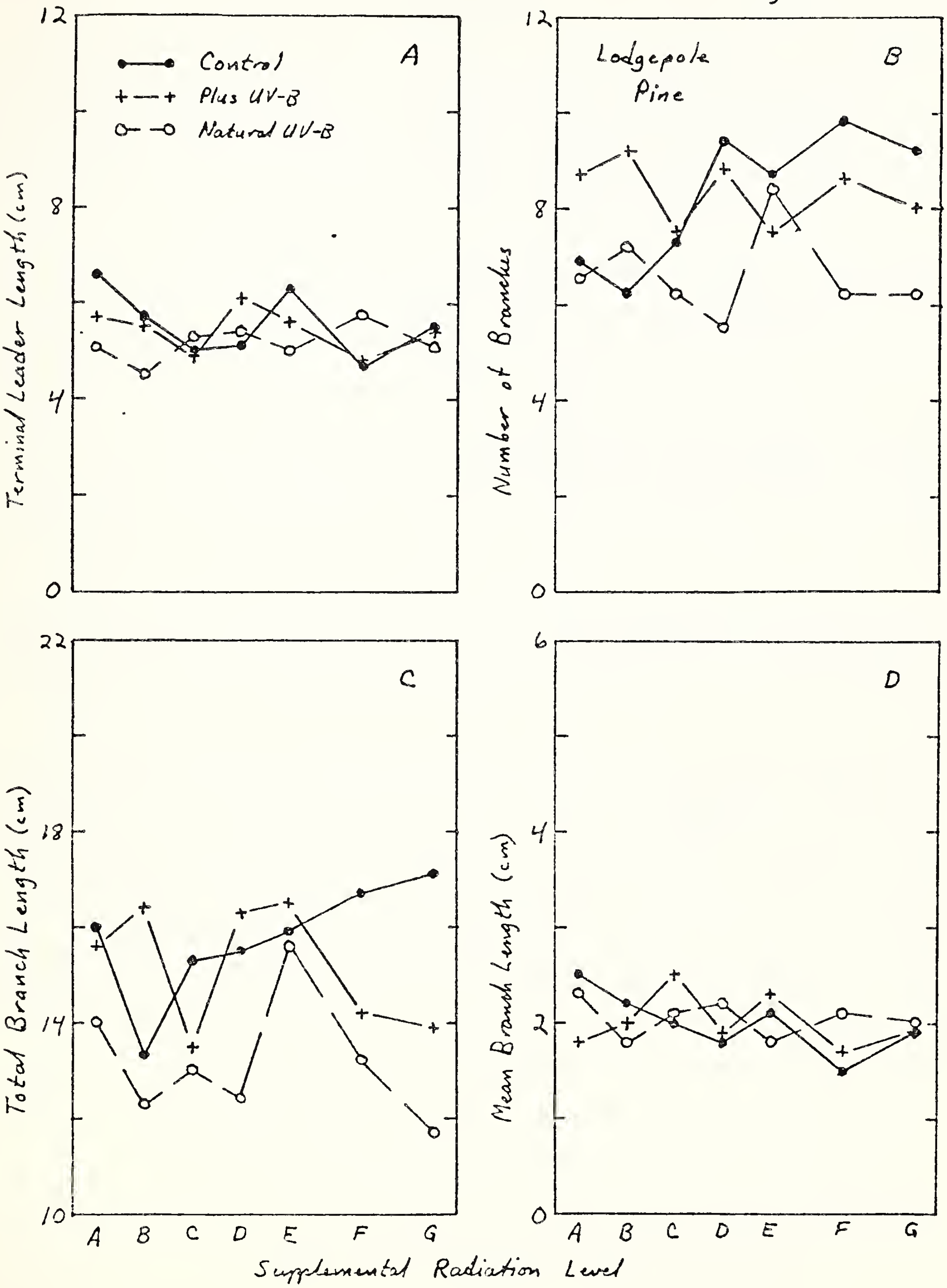
* N.S. = not significant at P = 0.05

Figure 2



Control
Plus UV-B
Natural UV-B
A
B
C
D
Engelmann Spruce
Terminal Leader Length (cm)
Number of Branches
Total Branch Length (cm)
Mean Branch Length (cm)
12
8
4
0
32
24
16
8
90
70
50
30
6
4
2
0
A B C D E F G
A B C D E F G
Supplemental Radiation Level

Figure 3



Control
Plus UV-B
Natural UV-B
A
B
C
D
Lodgepole Pine
Terminal Leader Length (cm)
Number of Branches
Total Branch Length (cm)
Mean Branch Length (cm)
Supplemental Radiation Level
A B C D E F G

study are judged to be minor and inconsequential for the 67-day treatment period.

DISCUSSION

Most effects of UV-B radiation on higher plants have been observed on herbaceous species. Studies on woody species have been very limited, although Biggs and Murphy (1977) reported damage of several conifers exposed to high UV-B levels shortly after germination. The effects of UV-B on tomato were cumulative (Caldwell et al., 1974). Hart et al. (1974) observed increased branching of chrysanthemums during exposure to UV-B.

From these and other studies, it was anticipated that UV-B treatment effects might appear on new foliage produced during a treatment period exceeding 2 months. Based on other research, particular attention was paid to stunting of needles and branches, color of foliage, and frequency of branching (e.g. dormancy break of buds and subsequent growth).

The nearly complete lack of response of Engelmann spruce and lodgepole pine to any of the treatments or radiation levels suggests two possibilities. First, neither species may be sensitive to the UV-B levels used during this study. Secondly, because of the perennial nature of these species, a treatment and observation period confined to a single growing season may be too short for effects to appear.

Ronco's (1970 a and b) observations that solar radiation damage of Engelmann spruce does not appear until the second growing season suggests that the second possibility is more realistic. Clearly, it is premature to conclude that UV-B has no effect on these two species.

It seems advisable to continue visual observations of the seedlings into the second growing season, and for this reason the plants were moved to the Fraser Experimental Forest where studies can be continued more conveniently. It has not yet been decided, however, if the plants should be subjected to the UV-B treatments again during the second growing season. It can be argued that continual treatment during successive growing seasons is most realistic, yet to do so would confound the second year's observations of carry-over first-year effects. High variability and limited numbers of seedlings per treatment prevent dividing the plants into two groups, one for observation and the second for retreatment.

REFERENCES

Biggs, R. H. and S. K. Murphy. 1971. Impact of solar UV-B radiation on crop productivity. Third Quarterly Report, EPA-BACER, 7 pp.

Caldwell, M. M., W. B. Sisson, F. M. Fox, and J. R. Brandle. 1974. Plant growth response to elevated UV irradiation under field and greenhouse conditions. Impacts of Climatic Change on the Biosphere. CIAP Mono. 5, pp. 4-253 to 4-259.

Hart, R. H., G. E. Carlson, H. H. Klueter, and H. R. Carns. 1974. Responses to economically valuable species to ultraviolet radiation. Impacts of Climatic Change on the Biosphere, CIAP Mono. 5, pp. 4-263 to 4-273.

Ronco, F. 1970a. Chlorosis of planted Engelmann spruce seedlings unrelated to nitrogen content. Can. J. Bot. 48:851-853.

Ronco, F. 1970b. Influence of high light intensity on survival of planted Engelmann spruce. For. Sci. 16:331-339.

REFERENCES

Biggs, R. H. and S. V. Kossuth. 1978. Impact of solar UV-B radi[illegible] crop productivity. Third Quarterly Report, EPA-IAG-D6, [illegible]

Caldwell, M. M., W. B. Sisson, F. M. Fox, and J. R. Brandle. 19[illegible] Plant growth response to elevated UV irradiation under field [illegible] greenhouse conditions. Impacts of Climatic Change on the Biosp[illegible] CIAP Mono. 5, pp. 4-253 to 4-259.

Hart, R. H., G. E. Carlson, H. H. Klueter, and H. R. Carns. [illegible] Responses to economically valuable species to ultraviolet [illegible] Impacts of Climatic Change on the Biosphere, CIAP Mono. 5, [illegible] 4-263 to 4-275.

[illegible], F. 1970a. Ontogeny of plants [illegible] on nitrogen content [illegible]

[illegible], F. 1970b. Influence of [illegible] Engelmann spruce [illegible]

APPENDIX

TABLE 6. EFFECT OF UV-B RADIATION LEVELS ON VEGETATIVE GROWTH OF ENGELMANN SPRUCE (ENHANCEMENT STUDY)
VALUES ARE MEANS AND STANDARD DEVIATIONS

Treatment	Radiation Level A	B	C	D	E	F	G
Terminal Leader Length (cm)							
Natural sun (control)	3.9 ± 2.1	3.8 ± 2.4	2.0 ± 1.5	2.4 ± 1.8	3.0 ± 2.0	6.2 ± 1.9	4.3 ± 0.6
Plus UV-B (cell. acetate)	2.8 ± 1.7	3.1 ± 2.6	3.9 ± 2.9	4.2 ± 2.2	2.1 ± 2.1	4.1 ± 1.2	6.3 ± 1.0
Natural UV-B (Mylar)	4.1 ± 2.6	3.3 ± 1.8	4.9 ± 2.1	3.0 ± 2.2	5.3 ± 0.7	2.4 ± 2.3	6.2 ± 2.0
No significant differences (P = 0.05)							
Number of Branches							
Natural sun (control)	24.2 ± 8.8	22.6 ± 9.1	17.0 ± 9.3	18.3 ± 5.7	18.4 ± 8.9	24.5 ± 13.4	17.3 ± 12.3
Plus UV-B (cell. acetate)	19.3 ± 8.8	14.7 ± 8.9	19.0 ± 6.6	18.0 ± 8.1	12.6 ± 5.8	15.5 ± 7.7	13.7 ± 12.5
Natural UV-B (Mylar)	16.1 ± 8.9	21.3 ± 7.9	14.9 ± 9.8	16.2 ± 8.5	20.3 ± 6.8	10.8 ± 5.0	19.3 ± 11.1
No significant differences (P = 0.05)							
Total Branch Length (cm)							
Natural sun (control)	71.9 ± 30.0	72.4 ± 33.9	49.6 ± 27.1	59.5 ± 21.7	63.8 ± 29.3	84.1 ± 41.4	60.4 ± 39.5
Plus UV-B (cell. acetate)	57.7 ± 23.6	43.9 ± 25.3	58.2 ± 18.4	55.5 ± 29.0	41.5 ± 22.4	45.5 ± 25.6	44.3 ± 35.5
Natural UV-B (Mylar)	50.5 ± 28.4	60.6 ± 24.0	47.1 ± 32.6	49.7 ± 27.2	64.7 ± 17.0	37.1 ± 18.4	68.0 ± 41.4
Natural sun significantly different from plus UV-B and natural UV-B (P = 0.05); no significant radiation effect							
Mean Branch Length (cm)							
Natural sun (control)	3.0 ± 0.6	3.3 ± 0.7	3.0 ± 0.6	3.2 ± 0.8	3.5 ± 0.5	3.6 ± 0.6	3.7 ± 0.9
Plus UV-B (cell. acetate)	3.1 ± 0.9	3.0 ± 0.6	3.2 ± 0.6	3.1 ± 0.5	3.2 ± 0.7	2.9 ± 0.6	3.8 ± 1.0
Natural UV-B (Mylar)	3.3 ± 1.0	2.8 ± 0.3	3.1 ± 0.5	3.1 ± 0.8	3.3 ± 0.4	3.4 ± 0.6	3.6 ± 0.7
Significant radiation effect (P = 0.05); no significant treatment differences.							

TABLE 6. EFFECT OF UV-B RADIATION LEVELS ON VEGETATIVE GROWTH OF ENGELMANN SPRUCE (ENHANCEMENT STUDY)
VALUES ARE MEANS AND STANDARD DEVIATIONS

Treatment	Radiation Level A	B	C	D	E	F	G
Terminal Leader Length (cm)							
Natural sun (control)	3.9 ± 2.1	3.8 ± 2.4	2.0 ± 1.5	2.4 ± 1.8	3.0 ± 2.0	6.2 ± 1.9	4.3 ± 0.6
Plus UV-B (cell. acetate)	2.8 ± 1.7	3.1 ± 2.6	3.9 ± 2.9	4.2 ± 2.2	2.1 ± 2.1	4.1 ± 1.2	6.3 ± 1.0
Natural UV-B (Mylar)	4.1 ± 2.6	3.3 ± 1.8	4.9 ± 2.1	3.0 ± 2.2	5.3 ± 0.7	2.4 ± 2.3	6.2 ± 2.0
No significant differences (P = 0.05)							
Number of Branches							
Natural sun (control)	24.2 ± 8.8	22.6 ± 9.1	17.0 ± 9.3	18.3 ± 5.7	18.4 ± 8.9	24.5 ± 13.4	17.3 ± 12.3
Plus UV-B (cell. acetate)	19.3 ± 8.8	14.7 ± 8.9	19.0 ± 6.6	18.0 ± 8.1	12.6 ± 5.8	15.5 ± 7.7	13.7 ± 12.5
Natural UV-B (Mylar)	16.1 ± 8.9	21.3 ± 7.9	14.9 ± 9.8	16.2 ± 8.5	20.3 ± 6.8	10.8 ± 5.0	19.3 ± 11.1
No significant differences (P = 0.05)							
Total Branch Length (cm)							
Natural sun (control)	71.9 ± 30.0	72.4 ± 33.9	49.6 ± 27.1	59.5 ± 21.7	63.8 ± 29.3	84.1 ± 41.4	60.4 ± 39.5
Plus UV-B (cell. acetate)	57.7 ± 23.6	43.9 ± 25.3	58.2 ± 18.4	55.5 ± 29.0	41.5 ± 22.4	45.5 ± 25.6	44.3 ± 35.5
Natural UV-B (Mylar)	50.5 ± 28.4	60.6 ± 24.0	47.1 ± 32.6	49.7 ± 27.2	64.7 ± 17.0	37.1 ± 18.4	68.0 ± 41.4
Natural sun significantly different from plus UV-B and natural UV-B (P = 0.05); no significant radiation effect							
Mean Branch Length (cm)							
Natural sun (control)	3.0 ± 0.6	3.3 ± 0.7	3.0 ± 0.6	3.2 ± 0.8	3.5 ± 0.5	3.6 ± 0.6	3.7 ± 0.9
Plus UV-B (cell. acetate)	3.1 ± 0.9	3.0 ± 0.6	3.2 ± 0.6	3.1 ± 0.5	3.2 ± 0.7	2.9 ± 0.6	3.8 ± 1.0
Natural UV-B (Mylar)	3.3 ± 1.0	2.8 ± 0.3	3.1 ± 0.5	3.1 ± 0.8	3.3 ± 0.4	3.4 ± 0.6	3.6 ± 0.7
Significant radiation effect (P = 0.05); no significant treatment differences.							

TABLE 7. EFFECT OF UV-B RADIATION LEVELS ON VEGETATIVE GROWTH OF LODGEPOLE PINE (ENHANCEMENT STUDY)
VALUES ARE MEANS AND STANDARD DEVIATIONS

Treatment	Radiation Level A	B	C	D	E	F	G
Terminal Leader Length (cm)							
Natural sun (control)	6.6 ± 2.1	5.7 ± 2.9	5.0 ± 2.3	5.1 ± 1.6	6.3 ± 1.7	4.7 ± 1.3	5.5 ± 2.0
Plus UV-B (cell. acetate)	5.7 ± 2.8	5.5 ± 3.0	4.9 + 1.7	6.1 ± 2.0	5.6 ± 2.9	4.8 ± 2.7	5.4 ± 3.0
Natural UV-B (Mylar)	5.1 ± 2.5	4.5 ± 1.7	5.3 ± 2.1	5.4 ± 2.4	5.0 ± 2.2	5.8 ± 3.7	5.1 ± 2.0
No significant differences (P = 0.05)							
Number of Branches							
Natural sun (control)	6.9 ± 3.8	6.2 ± 3.2	7.3 ± 3.7	9.4 ± 4.7	8.7 ± 3.9	9.8 ± 5.6	9.2 ± 3.6
Plus UV-B (cell. acetate)	8.7 ± 3.1	9.2 ± 3.8	7.5 ± 4.3	8.8 ± 3.0	7.5 ± 3.4	8.6 ± 3.1	8.0 ± 4.7
Natural UV-B (Mylar)	6.5 ± 3.3	7.2 ± 2.7	6.2 ± 2.9	5.5 ± 2.3	8.4 ± 4.8	6.2 ± 2.6	6.2 ± 2.8
Natural UV-B significantly different from natural sun and plus UV-B (P = 0.05); no significant radiation effect							
Total Branch Length (cm)							
Natural sun (control)	16.0 ± 6.8	13.3 ± 6.9	15.3 ± 8.9	15.5 ± 6.3	15.9 ± 5.8	16.7 ± 14.7	17.1 ± 6.8
Plus UV-B (cell. acetate)	15.6 ± 6.5	16.4 ± 7.3	13.5 ± 6.1	16.3 ± 6.7	16.5 ± 8.5	14.2 ± 8.2	13.9 ± 11.0
Natural UV-B (Mylar)	14.0 ± 10.0	12.3 ± 4.6	13.0 ± 6.6	12.4 ± 7.0	15.6 ± 11.0	13.2 ± 7.1	10.7 ± 3.7
No significant differences (P = 0.05)							
Mean Branch Length (cm)							
Natural sun (control)	2.5 ± 1.0	2.2 ± 0.5	2.0 ± 0.5	1.8 ± 0.5	2.1 ± 0.8	1.5 ± 0.5	1.9 ± 0.5
Plus UV-B (cell. acetate)	1.8 ± 0.6	2.0 ± 1.3	2.5 ± 2.2	1.9 ± 0.6	2.3 ± 0.8	1.7 ± 0.9	1.9 ± 1.6
Natural UV-B (Mylar)	2.3 ± 1.1	1.8 ± 0.7	2.1 ± 0.8	2.2 ± 0.8	1.8 ± 0.5	2.1 ± 0.8	2.0 ± 1.0
No significant differences (P = 0.05)							